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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
15 February 2001 (15.02.2001)

PCT

(10) International Publication Number
WO 01/10677 A2

- (51) International Patent Classification⁷: B60R (74) Agent: PRESTA, Frank, P.; Nixon & Vanderhye P.C., Suite 800, 1100 North Glebe Road, Arlington, VA 22201-4714 (US).
- (21) International Application Number: PCT/US00/21656
- (22) International Filing Date: 9 August 2000 (09.08.2000) (81) Designated States (*national*): BR, CA, JP, KR, MX.
- (25) Filing Language: English (84) Designated States (*regional*): European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).
- (26) Publication Language: English
- (30) Priority Data: 09/370,171 9 August 1999 (09.08.1999) US Published:
— Without international search report and to be republished upon receipt of that report.
- (71) Applicant: ATLANTIC RESEARCH CORPORATION [US/US]; 5956 Wellington Road, Gainesville, VA 22155-1699 (US). For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.
- (72) Inventors: NEIDERT, Jamie, B.; 3175 Southhampton Drive, Jeffersonston, VA 22724 (US). BLACK, Robert, E.; 14603 Farm Pond Court, Centreville, VA 20120 (US).



WO 01/10677 A2

(54) Title: GAS GENERATOR FOR EXPELLING HALON REPLACEMENTS

(57) Abstract: A gas generator capable of quickly producing a large quantity of substantially solids-free nontoxic gas useful as a propellant in halon replacement fire suppression systems is provided. The double base castable propellant composition is formulated from a major amount of ammonium nitrate, a minor amount of nitrocellulose, at least one selected high energy nitrate ester plasticizer, a thermal scavenger, and at least one burning rate modification and control additive to achieve a burning rate of 0.2 inches per second or greater at 1000 psia. The burning rate is further enhanced by the configuration of the solid propellant, which is formed to have dimensions selected to enhance the burning rate. The gas generator composition and physical arrangement synergistically produce an optimally rapid burning rate.

GAS GENERATOR FOR EXPELLING HALON REPLACEMENTS

Technical Field

The present invention is directed generally to gas generator propellant compositions and specifically to a fast burning, low temperature gas generator useful for heating and expelling halon replacements, in fire suppression systems and the like.

Background of the Invention

The Montreal Protocol of 1987 and, subsequently, the 1990 London Amendment and the 1992 Copenhagen Amendment called for the phaseout of halons by 1994. Fire extinguishing systems for most military and commercial applications suffer from the fact that they use ozone-depleting substances (Halon and similar fluorocarbons). Available liquid agents which do not exhibit the high ozone-depleting potential (ODP) of Halon and thus are currently considered as direct substitutes for Halon have several drawbacks; they require excessively large, heavy installations, they are not as effective as Halon; they require regular checks to assure pressures are maintained; and some are more toxic than Halon. The future result therefore could be less efficient fire suppression for many applications such as automobiles, aircraft, ground vehicles, inhabited marine systems, off-shore drilling operations, buildings and many others.

Halon replacements are typically less volatile than Halon. Gas generators can aid in dispensing and vaporizing these agents so that the fire suppressant is more efficiently distributed. The gas generant should generate large amounts of gas and possess chemical balance upon combustion ($O/F=1$) to avoid the pressure of excess oxygen, should not generate toxic products and should burn readily and completely.

The development of halon replacements for fire suppression and other purposes that are environmentally friendly has been addressed by the prior art. In U.S. Patent No. 5,423,384, for example, Galbraith et al., disclose a fire suppression apparatus for effectively delivering a fire suppressant that is less

environmentally hazardous than a halon. The apparatus described by Galbraith et al. preferably uses a solid propellant of the type used in automotive air bags as a gas generator. The preferred solid propellants are based on 5-aminotetrazole, guanidine nitrate and sodium azide and are mixtures of compacted powders. The gas generating reactions of the preferred propellants, which yield over 2.0 moles of gas per 100 grams, generally do not occur efficiently at temperatures below about 2000°F (1093°C). The "burn tone" of these propellants is varied by changing their physical form.

U.S. Patent No. 5,425,886 to Smith discloses an on-demand nonhalon fire extinguishing system useful primarily for hydrocarbon fuel storage tanks in military applications. This system uses a gas generator with a propellant/explosive mixture that is actuated to produce and release a mixture of inert, nonoxidizing nitrogen, carbon dioxide and carbon monoxide gases and water vapor. The reaction times to produce the gaseous products are typically milliseconds instead of the microseconds characteristic of high performance explosives. In the system described in this patent, propellant and fire suppression functions are performed by the same composition.

Thompson et al. disclose double base plateau and mesa burning propellants with a mixture of bismuth and copper salts of hydroxy-substituted benzoic acids added to modify the burn rate in U.S. Patent No. 5,652,409. A mixture of both a bismuth acid salt and a copper acid salt is required to produce the desired plateau or mesa effect. The use of a bismuth acid salt or a monobasic copper salicylate alone is stated to slow the burning rate slightly, but will not produce a plateau or mesa effect. The addition of monobasic copper 2,4-dihydroxybenzoate alone will produce a plateau and slight mesa, but at a pressure too low for many desired applications. U.S. Patent No. 5,639,987 to Bertileau et al. also discloses compositions for modifying the ballistic properties (burning rate) of double base or nitro-plasticized double base solid propellants that include a bismuth compound and a copper compound. Propellants with the burning rate characteristics described in these patents are not

the most effective gas generators for expelling halon replacements in fire suppression systems.

In U.S. Patent No. 5,372,664, Neidert et al. describe modifying the burn rate of a double base solid propellant to
5 achieve controllable plateau and mesa burning rate characteristics by the addition of carbon fibers to the propellant composition. Like the compositions described in U.S. Patent No. 5,652,409 to Thompson et al., however, the burning rate modifiers disclosed by Berteleau et al. and Neidert et al.
10 produce a plateau effect that is not particularly suitable for gas generators for fire suppression and similar systems where a rapid burning rate is required.

U.S. Patent No. 5,076,868 to Doll et al. discloses high performance, low cost solid propellants that produce
15 halogen-free exhaust. Although these propellants have a low burn rate pressure exponent, they are designed primarily to achieve complete combustion. Their composition and burn rate are not desirable for gas generants for use in connection with fire suppression systems.

The prior art presents many other examples of double base
20 gas generator or propellant compositions and methods for preparing these compositions. U.S. Patent No. 4,082,583 to Mosher and Statutory Invention Registration No. 141341 to Hughes et al. are exemplary of this art. Hughes et al. describes a
25 propellant with a long working life or potlife that employs organobismuth compounds to achieve this result and relies on a crosslinker to improve mechanical properties. Mosher discloses a solventless method of preparing nitrocellulose-based propellants using a thin slurry of nitrocellulose in about ten
30 times as much warm water to which desired components are added in solution. The water must be removed before the resulting paste can be aged and processed further to produce the propellant.

None of the foregoing references suggests either a
35 propellant with an optimum composition and ballistic properties to function as a gas generant in a nonhalon fire suppression system or a method for making such a propellant which employs a

solventless slurry that maintains optimum flow properties at ambient temperatures to produce desired mechanical properties without the use of crosslinking agents or involved processing steps. Neither does the prior art suggest a configuration for a
5 gas generator that is designed to enhance the speed of the propellant burning rate.

A need exists, therefore, for a uniquely configured gas generator employing propellant compositions with optimum ballistic properties, particularly a fast burning rate, and
10 mechanical properties for use with nonhalon fire suppression and other propellant-driven systems. A need also exists for a method of making such propellants and gas generators.

SUMMARY OF THE INVENTION

It is a primary object, therefore, to overcome the
15 disadvantages of the prior art and to provide a uniquely configured gas generator employing propellant compositions with optimum ballistic and mechanical properties for use with nonhalon fire suppression and other propellant driven systems.

It is another object of the present invention to provide a
20 gas generator propellant composition useful with nonhalon fire suppression compositions with a burning rate selected to produce optimally quick release of the nonhalon fire suppression composition.

It is a further object of the present invention to provide
25 a uniquely configured end sized gas generator which, when activated and ignited burns at an optimum fast burning rate.

It is still another object of the present invention to provide a gas generator propellant composition with optimum gas output, flame temperature, and burning rate exponent for fire
30 and explosion suppression applications.

It is still a further object of the present invention to provide a castable gas generator propellant composition which produces a balanced, nontoxic, substantially solids-free exhaust.

35 It is yet another object of the present invention to provide gas generator propellant compositions designed effective

for use in emergency fire suppression systems in critical spaces of military and commercial vehicles, engines and buildings.

It is yet a further object of the present invention to provide a method for making a castable gas generator that
5 produces desired mechanical properties without the use of crosslinking agents.

In accordance with the aforesaid objects, a gas generator designed for the effective production of a propellant suitable for use in nonhalon fire suppression and like systems is
10 provided. The gas generator propellant compositions of the present invention have a burning rate of at least 0.2 inches per second or greater at 1000 psia, and a low flame temperature and produce an optimally desirable large quantity of a nontoxic, balanced exhaust. Preferred gas generator propellant
15 compositions are double base nitrocellulose plastisol compositions preferably including a selected bismuth compound for burning rate modification and control. The gas generator of the present invention is cast to have a configuration and mechanical properties that enhance the high burning rate
20 required for fire suppression applications. The gas generator composition is cast into flexible, substantially rectangular grains of selected optimum thickness and longitudinal dimensions. These are formed into carpet rolls which are supported concentrically with rigid sleeves mounted at a
25 selected radial distance apart in a motor or like device, in a fire suppression or similar system.

Other objects and advantages will be apparent from the following detailed description, claims and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

30 Figure 1 is a graphic representation of burning rate at selected pressures for a preferred gas generator composition of the present invention;

Figure 2 is a perspective view of a preferred configuration of a gas generator element of the present invention;

35 Figure 3 is a cross-sectional view of the gas generator of the present invention taken along line 3-3 of Figure 4; and

Figure 4 is a side cross-sectional schematic view of an end of a fire suppression device showing the gas generator of the present invention mounted in place.

DETAILED DESCRIPTION OF THE INVENTION

5 Gas generator propellant compositions useful for efficiently expelling halon replacements in fire suppression systems must burn quickly and cleanly in response to activation to expel the fire suppressant chemical to extinguish a fire. Typically in such systems, a gas generator is activated to
10 generate pressure within the fire suppressant so that substantially all of the suppressant in the system will be expelled. The gas generator propellant composition must burn as quickly as possible after activation for optimum operation of the fire suppression system. In addition, the gas generator
15 must ideally produce a large useful amount of a nontoxic, balanced exhaust. The gas generator of the present invention achieves these objectives by a unique synergy of composition and structure. The gas generator compositions of the present invention are formulated chemically to produce a high burning
20 rate and are also physically configured to form gas generator elements sized and mounted to enhance the burning rate.

The gas generator compositions of the present invention optimally should have a substantially solids-free gas output of greater than 3 moles per 100 grams of propellant. This gas
25 output should be nontoxic and, particularly, free of nitrogen oxide (NO) and carbon monoxide (CO). The oxygen to fuel ratio (O:F) should be balanced with O:F=1. The flame temperature and the burning rate exponent should be low, less than 2800°K and less than 0.8, respectively. A family of gas generator
30 propellant compositions with these desired properties has been developed. This family of gas generator propellants employs a double base binder composed of nitrocellulose (NC) plasticized with at least one high energy nitrate ester and mixed with ammonium nitrate (AN) and selected processing aids.

35 Preferred high energy nitrate ester plasticizers for this purpose include butanetriol trinitrate (BTTN), triethyleneglycol dinitrate (TEGDN) and triacetin. Other nitrate esters,

including, but not limited to, diethyleneglycol dinitrate (DEGDN), trimethylol trinitrate (TMETN), nitroglycerin (NG), liquid analogs of nitroglycerine and butylnitrate ester nitramine (butyl NENA) may also be suitable for use in the gas generator propellant compositions of the present invention.

A thermal stabilizer, preferably para-N-methylnitroaniline (MNA) is one of the preferred processing aids used in the gas generator propellant compositions of the present invention. Other thermal stabilizers, notably 2-nitro-phenylamine (2-NPA), 4-nitrodiphenylamine (4-NDPA) and diphenylamine (DPA) may also be useful.

The burning rate of the gas generator propellants of the present invention can be effectively modulated by including carbon with the formulation of the present invention. A small amount of carbon, preferably in the form of carbon black, therefore, is included.

The burning rate of at least 0.2, and preferably in excess of 0.2, inches per second at 1000 psia required for the optimum functioning of the present gas generator propellants in halon replacement fire suppression systems may be achieved by the addition to the propellant formulation of a bismuth compound, preferably bismuth oxide (Bi_2O_3) or bismuth subsalicylate. Other suitable bismuth and copper compounds may also be used.

The gas generator propellant compositions of the present invention will preferably contain 10 to 20% by weight nitrocellulose (NC), 19 to 34% by weight butanetriol trinitrate (BTTN), 55 to 74% by weight ammonium nitrate (AN), 0.9-2.0% by weight para-N-methylnitroaniline (MNA) and 0.1 to 0.4% by weight carbon. Optional additional components include triethyleneglycol dinitrate (TEGDN) or another nitrate ester, triacetin and either bismuth oxide or bismuth subsalicylate. Triacetin is preferably added at about 2.0% by weight, and the selected bismuth compound at 1.0 to 2.2% by weight.

Table 1 below sets forth various gas generator propellant composition formulations in accordance with the present invention and the properties of these formulations.

TABLE 1

COMPOSITION	A	B	C	D	E	F	G	H	I	J
NC, %	11.5	19.75	10.0	14.0	10.0	10.0	10.0	10.0	10.0	10.0
BTN, %	-	19.75	34.0	28.0	29.5	24.3	22.5	29.5	24.3	22.5
TEGDN, %	13.5	-	-	-	-	-	-	-	-	-
Triacetin, %	-	-	-	-	-	2.0	2.0	-	2.0	2.0
AN, %	74.0	59.5	55.0	57.0	57.0	61.5	62.0	57.0	61.5	62.0
MNA, %	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Carbon, %	0.1	0.1	0.1	0.1	0.4	0.2	0.4	0.4	0.2	0.4
Bi ₂ O ₃ , %	-	-	-	-	2.2	1.1	2.2	-	-	-
Bismuth Subsalicylate, %	-	-	-	-	-	-	-	2.2	1.1	2.2
T _c , K	2508	2730	2802	2770	2745	2692	2672	2745	2692	2672
Moles of Gas	4.1	3.9	3.9	3.9	3.8	3.9	3.9	3.8	3.9	3.9
% Solids	0	0	0	0	2.0	1.0	1.6	2.0	1.0	1.6
r _b at 1000 psia, in/sec	-	-	0.27	0.25	-	-	-	-	-	-
exponent at 1000 psia	-	-	0.8	1.0	1.0	0.78	1.0	1.0	0.90	0.90

Composition F represents a most preferred embodiment of the present invention. Composition F has the following formulation:

	10.0%	NC
5	24.3%	BTTN
	2.0%	Triacetin
	61.5%	AN
	0.9%	MNA
	0.2%	Carbon
10	1.1%	Bi ₂ O ₃

This propellant formulation has a flame temperature, T_c , of 2692°K and a burning rate exponent of 0.78 at 1000 psia. 3.9 moles of gas are produced for each 100 grams of propellant, while 1.0% by weight solids is produced. A
15 flame temperature less than 2800°K and a burning rate exponent of 0.8 or less are optimum for a gas generator for the fire suppression applications described above. A propellant with this formulation will autoignite at about 190°F which makes it most suitable for lower temperature
20 applications.

Figure 1 represents burning rate data for Composition F at pressures from 500 to 4000 psia for several batches of propellant produced according to this formulation. The desired optimum burning rate for this type of gas generator
25 is at least 0.2 inches per second and preferably greater, which was achieved by all but two of the Composition F formulations tested.

Processing for the family of propellants of the present invention is advantageous and unique. Most highly filled
30 solid propellants exhibit end-of-mix viscosities (EOMV) that range from 2.0 to 10.0 kilopoise (kP) and have finite effective working lives or potlives. The present family of plastisol formulations does not rely on classic crosslinking, such as that exhibited by epoxy or
35 polyurethane binders, to achieve physical integrity.

Plastisol nitrocellulose (PNC) behaves as a thermoplastic; hydrogen bonding and intrinsic viscosity provide the physical integrity for the final product. The nitrocellulose is added to the selected nitrate ester or
5 esters in a liquid form with a thermal stabilizer, preferably N-methylnitroaniline (MNA). Carbon, preferably in the form of carbon black, and the necessary complement of ammonium nitrate (AN) are added to this blend.

The mixture is mixed at a temperature within the range
10 of 60 to 80°F until an optimum viscosity is attained. Ideally, the viscosity should be about 1.0 kP, preferably from 0.4 to 2.0 kP, to maintain the homogeneity of the mixture and to preclude settling of solid additives. High viscosity nitrocellulose pastes are not required to achieve
15 the high levels of PNC required for the present propellant formulation. The present PNC mixtures can be processed in standard vertical mixer equipment. The flexibility of this processing method, moreover, allows for unplanned interruptions of the process without waste. The desired
20 liquid nitrate ester, for example, butanetriol trinitrate (BTTN) or triethyleneglycol trinitrate (TEGDN), is preferably mixed with an inert plasticizer, preferably triacetin (TA), to produce a solvent-less slurry. The triacetin also makes the formulation castable.

25 This slurry maintains its flow properties, provided that the processing temperatures are maintained below 100°F. Processing temperatures of 60 to 80°F are preferred. The slurry viscosity will show little increase unless temperatures higher than 100°F are achieved and maintained.
30 The slurry may then be cast into a desired configuration and cured. Once the compositions of the present invention cure, the resultant propellants exhibit exceptional mechanical properties, and an extended working life or potlife.

Figure 2 illustrates, in perspective view, a preferred
35 configuration into which the propellant compositions of the

present invention may be cast to form a gas generator element 10. The gas generator element 10 is preferably rectangular in shape as shown. The components of the propellant formulation make this element flexible so that it resembles a stick of chewing gum. The length a of the rectangular element 10 is selected to correspond approximately to the circumference of a central support sleeve in the gas generator as described below. The width b of the rectangular element 10 is selected to correspond to the distance between the support sleeves in the gas generator. The thickness c of the gas generator element 10 is a critical dimension.

The gas generator must burn quickly within a required time. If the gas generator element is too thick, the propellant will not burn quickly enough, while if the gas generator element is too thin, it is likely to burn too quickly. The thickness c of the rectangular gas generator element 10 should be 0.050 to 0.500 inches, preferably 0.060 inches, to burn optimally depending on the requirements of the device. A thickness of 0.080 inches was tested and found to be too thick to burn efficiently. The optimum length a of the gas generator element used in a halon replacement fire suppression system has been found to be about 4.5 inches, and the optimum width will be about 1.5 inches. Other dimensions may be more effective in other applications.

A number of gas generator elements 10 are optimally supported in the concentric ring arrangement shown in Figure 3. This arrangement employs three radially spaced concentric cylindrical sleeves 12, 14 and 16 to form a gas generator assembly 18. The sleeves are preferably formed of sheet metal or a similar material. Each sleeve 12, 14 and 16 supports what is referred to in the art as a carpet roll of the solid propellant forming a gas generator element 10a, 10b or 10c. The length of each flexible gas generator element 10 is selected to correspond approximately to the

circumference of the radially outermost sleeve 12, which has a greater circumference than that of the radially inward sleeves 14 and 16. The lengths of the gas generator elements 10b and 10c may be cut as required to correspond to the circumferences of and to fit within the sleeves 14 and 16 respectively. The flexibility of the solid propellant material facilitates this.

Figure 4 illustrates a side cross-sectional schematic view of the gas generator assembly 18 mounted in place in the housing 20 of a fire suppression apparatus 22. The plurality of gas generator elements 10 required to cover the lengths of the concentric sleeves 12, 14 and 16 of the gas generator assembly 18 can be clearly seen in Figure 4. The number of gas generator elements 10 required to substantially cover longitudinally each sleeve 12, 14 and 16 will depend on the dimensions of the gas generator assembly 18. The flexibility of the solid propellant composition allows each gas generator element to be cut to the correct size required.

The gas generator assembly 18 can be effectively used as gas generator 6 in the fire and explosion suppressant systems shown and described in U.S. Patent No. 5,660,236 to Sears et al. The disclosure of U.S. Patent No. 5,660,236 is hereby incorporated herein by reference.

The gas generator propellant compositions of the present invention have been described primarily with respect to their application in fire suppression systems, particularly nonhalon or halon replacement systems. This description is not intended to be limiting, however. The solid flexible gas generator elements of the present invention will be useful for any propellant or gas-generating applications without drastic temperature requirements where a clean, fast burning gas generator is required.

INDUSTRIAL APPLICABILITY

The gas generators of the present invention will find their primary application as propellants in halon replacement fire suppression systems. These gas generators
5 will also be useful in applications requiring a physically versatile solid propellant formulation that quickly produces a large volume of substantially solids-free nontoxic gas.

WHAT IS CLAIMED IS:

1 1. A quick burning gas generator characterized by the
2 rapid production of a large amount of substantially
3 solids-free nontoxic gas comprising a double base castable
4 propellant composition formulated to produce a flexible
5 solid gas generator having a burning rate of at least 0.2
6 inches per second or greater at 1000 psia and having a
7 configuration sized and dimensionally positioned to enhance
8 rapid burning of the gas generator.

1 2. The gas generator described in claim 1, wherein
2 said double base propellant composition formulation
3 comprises a major amount of ammonium nitrate and a minor
4 amount of nitrocellulose, at least one selected high energy
5 nitrate ester plasticizer, a thermal scavenger and at least
6 one burning rate modification and control additive, wherein
7 the components of said formulation are selected to produce a
8 balanced fuel to oxygen ratio, a flame temperature below
9 2800°K and a pressure exponent of 0.8 or less at 1000 psia.

1 3. The gas generator described in claim 2, wherein
2 said at least one high energy nitrate ester plasticizer is
3 selected from the group consisting of butanetriol
4 trinitrate, triethyleneglycol dinitrate, triacetin,
5 diethyleneglycol, dinitrate, trimethylol trinitrate,
6 nitroglycerine liquid analogs of nitroglycerine, and
7 butylnitrate ester nitramine.

1 4. The gas generator described in claim 3, wherein
2 said thermal scavenger is selected from the group consisting
3 of para-N-methylnitroaniline, 2-nitro-phenylamine,
4 4-nitrodiphenylamine, and diphenylamine.

1 5. The gas generator described in claim 4, wherein
2 the said at least one burning rate modification and control
3 additive is selected from the group consisting of carbon,
4 bismuth oxide and bismuth subsalicylate.

1 6. The gas generator described in claim 5, wherein
2 said at least one high energy nitrate ester plasticizer is

3 selected from the group consisting of butanetriol
4 trinitrate, triethyleneglycol dinitrate and triacetin, said
5 thermal scavenger is para-N-methylnitroaniline, and said
6 burning rate modification and control additive is carbon.

1 7. The gas generator described in claim 5, wherein
2 said at least one high energy nitrate ester plasticizer is
3 selected from the group consisting of butanetriol
4 trinitrate, triethyleneglycol dinitrate and triacetin, said
5 thermal scavenger is para-N-methylnitroaniline, and said
6 burning rate modification and control additives are carbon
7 and bismuth oxide.

1 8. The gas generator described in claim 5, wherein
2 said at least one high energy nitrate ester plasticizer is
3 selected from the group consisting of butanetriol
4 trinitrate, triethyleneglycol dinitrate and triacetin, said
5 thermal scavenger is para-N-methylnitroaniline, and said
6 burning rate modification and control additives are carbon
7 and bismuth subsalicylate.

1 9. The gas generator described in claim 6 wherein
2 said high energy nitrate ester plasticizers are butanetriol
3 trinitrate and triacetin and said burning rate modification
4 and control additives are carbon and bismuth oxide.

1 10. The gas generator described in claim 6, wherein
2 said high energy nitrate ester plasticizers are butanetriol
3 trinitrate and triacetin and said burning rate modification
4 and control additives are carbon and bismuth subsalicylate.

1 11. The gas generator described in claim 6, wherein
2 said high energy nitrate ester plasticizer is
3 triethyleneglycol dinitrate and said burning rate
4 modification and control additive is carbon.

1 12. The gas generator described in claim 2, wherein
2 said double base propellant composition comprises 55 to 74%
3 by weight ammonium nitrate, 10 to 20% by weight
4 nitrocellulose, 13 to 34% by weight high energy nitrate
5 ester plasticizer, 0.9 to 2.0% by weight thermal scavenger,

6 and 0.1 to 2.2% by weight burning rate modification and
7 control additive.

1 13. The gas generator described in claim 12, wherein
2 said double base propellant composition comprises 61.5% by
3 weight ammonium nitrate, 10.0% by weight nitrocellulose,
4 26.3% by weight high energy nitrate ester plasticizer, 0.9
5 to 2.0% by weight thermal scavenger and 1.3% by weight
6 burning rate modification and control additive.

1 14. The gas generator described in claims 13, wherein
2 said high energy nitrate ester plasticizer comprises
3 butanetriol trinitrate and triacetin, said thermal scavenger
4 comprises para-N-methylnitroaniline, and said burning rate
5 modification and control additives comprise carbon and
6 bismuth oxide.

1 15. The gas generator described in claim 1, wherein
2 said propellant formulation is castable to produce a
3 flexible substantially rectangular configuration having a
4 thickness selected to enhance rapid burning of the gas
5 generator.

1 16. The gas generator described in claim 15, wherein
2 said selected thickness is 0.050 to 0.500 inches.

1 17. The gas generator described in claim 16, wherein
2 said selected thickness is 0.060 inches.

1 18. A castable solid double base propellant
2 composition comprising 61.5% by weight ammonium nitrate,
3 10.0% by weight nitrocellulose, 24.3% by weight butanetriol
4 trinitrate, 2.0% by weight triacetin, 0.9% by weight
5 para-N-methylnitroaniline, 0.2% carbon and 1.1% bismuth
6 oxide.

1 19. A clean, low temperature gas generator assembly
2 capable of rapidly producing a balanced gas output in excess
3 of 3 moles for each 100 grams of gas generator propellant
4 composition comprising a plurality of axially extending
5 concentric sleeve supports, each of said sleeve supports
6 being mounted a selected radial distance apart and
7 positioned concentrically to support a plurality of gas

8 generator elements sized and positioned adjacent to a
9 surface of each of said sleeve supports to substantially
10 cover said sleeve support, wherein each said gas generator
11 element comprises a flexible substantially rectangularly
12 shaped solid propellant, wherein the longest dimension of
13 the rectangle corresponds approximately to the largest
14 circumference of a sleeve support, and said solid propellant
15 forming said gas generator has a thickness and composition
16 formulated to burn rapidly at a rate of at least 0.2 inches
17 per second or greater at 1000 psia.

1 20. The gas generator assembly described in claim 19,
2 wherein said propellant thickness is 0.050 to 0.500 inches
3 and said propellant composition formulation comprises a
4 major amount of ammonium nitrate and a minor amount of
5 nitrocellulose, at least one selected high energy nitrate
6 ester plasticizer, a thermal scavenger and at least one
7 burning rate modification and control additive, wherein the
8 components of said formulation are selected to produce a
9 balanced fuel to oxygen ratio, a flame temperature below
10 2800°K and a pressure exponent of 0.8 or less at 1000 psia.

1 21. A method of making the gas generator described in
2 claim 2, including the steps of:

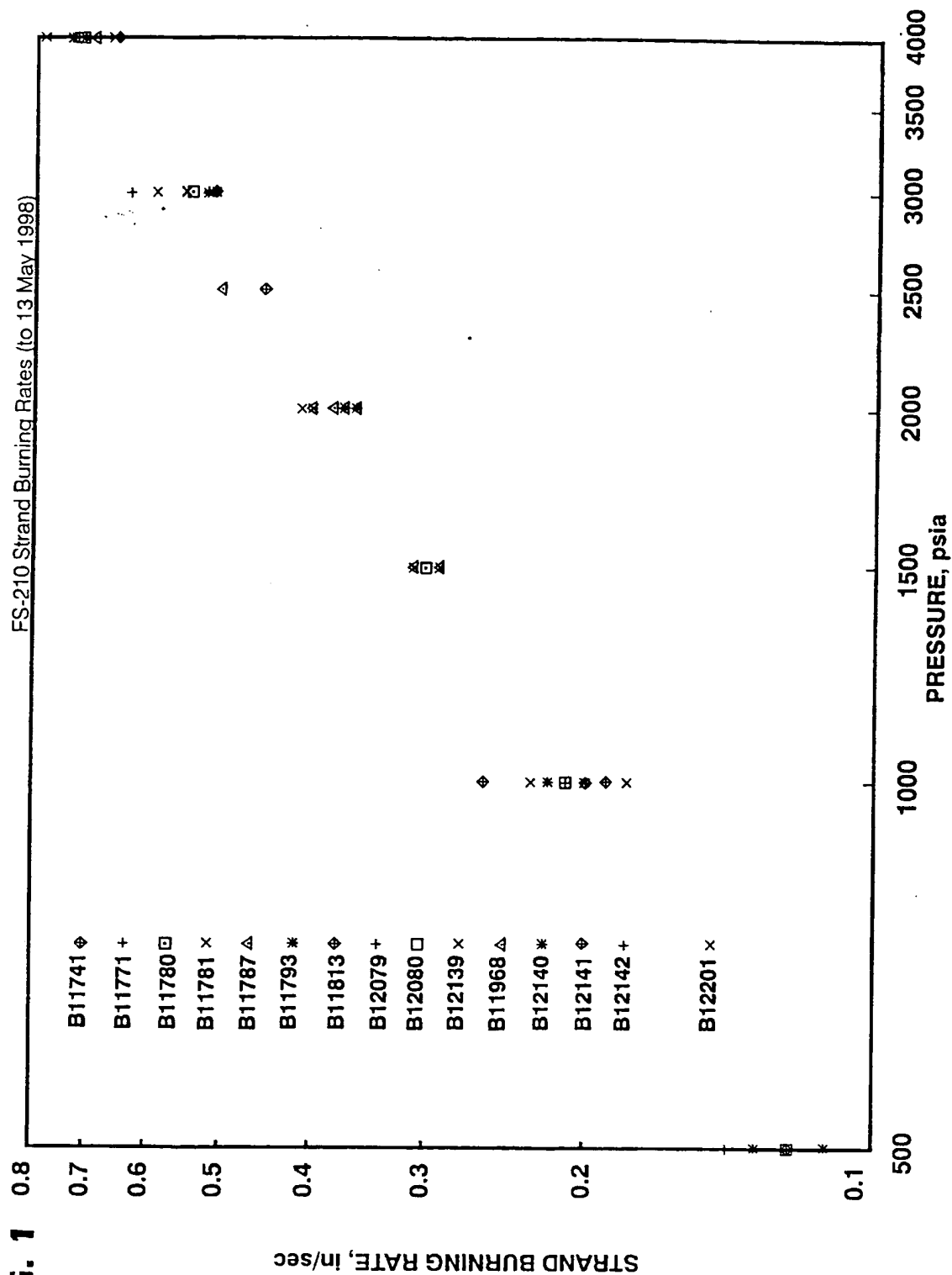
3 (a) adding nitrocellulose to a blend of at least
4 one high energy nitrate ester plasticiser and said thermal
5 stabilizer to produce a solvent-less slurry;

6 (b) adding to the solvent-less slurry, ammonium
7 nitrate and at least one burning rate modification and
8 control additive;

9 (c) mixing the mixture formed in step (b) at a
10 temperature sufficiently low to maintain a homogenous
11 mixture until the viscosity of the mixture is greater than
12 about 1.0 kP; and

13 (d) curing the resulting product to produce a
14 solid, flexible propellant composition.

1 22. The method described in claim 21, wherein said
2 thermal scavenger comprises para-N-methylnitroaniline, said
3 high energy nitrate plasticizer comprises butanetriol
4 trinitrate and triacetin, and said burning rate modification
5 and control additive comprises carbon and bismuth oxide.



2/2

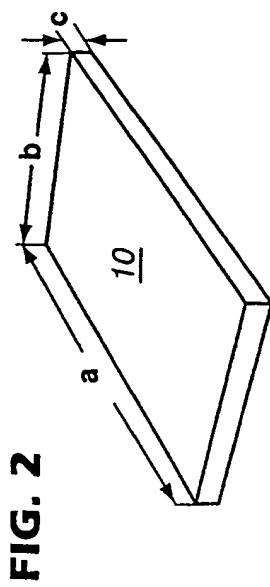
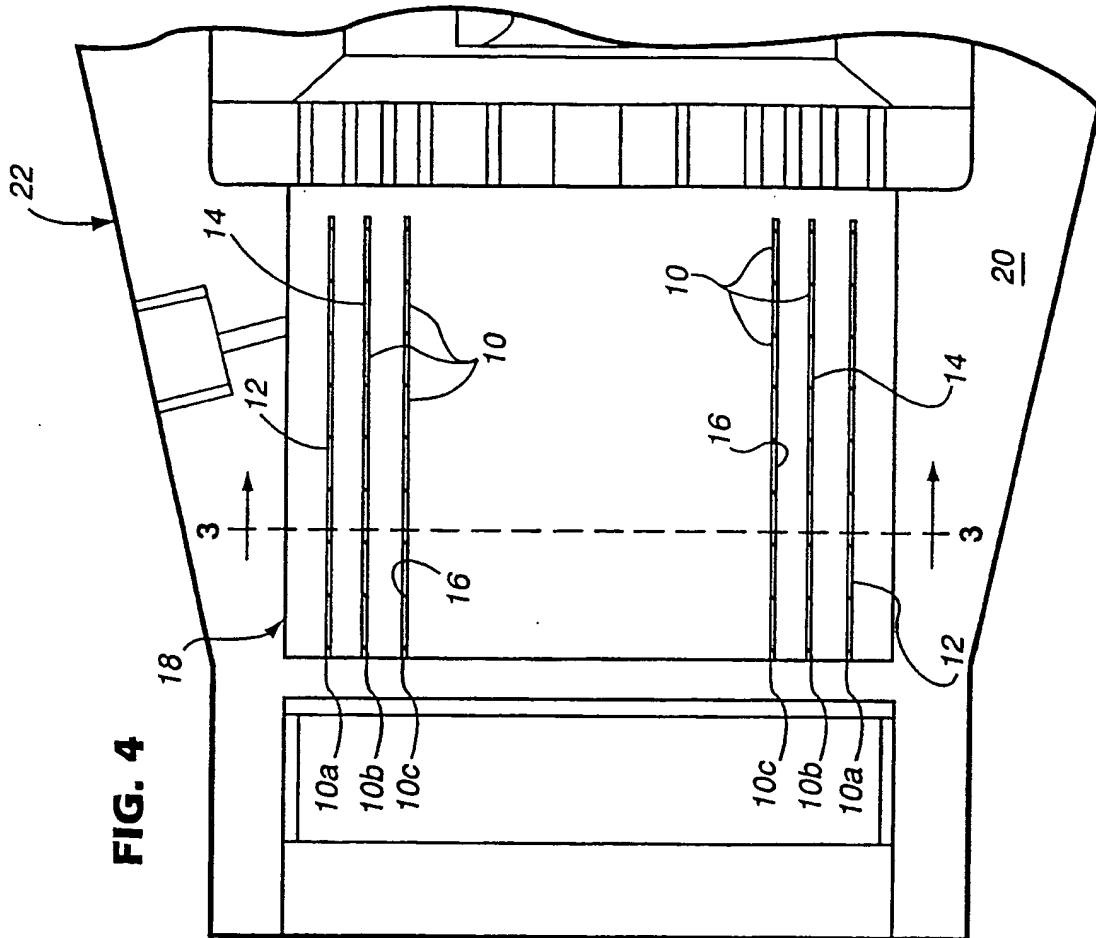


FIG. 3

